INTERNATIONAL JOURNAL OF CLIMATOLOGY
Int. J. Climatol. 20: 105–114 (2000)

FORECASTING INDIAN SUMMER MONSOON RAINFALL BY OUTGOING LONGWAVE RADIATION OVER THE INDIAN OCEAN

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Received 16 November 1998
Revised 10 April 1999
Accepted 9 May 1999

ABSTRACT

The satellite derived outgoing longwave radiation (OLR) over the Indian Ocean (30°N–30°S and 40°E–100°E) from 1974 to 1996 has been analysed for the relationship with the Indian summer monsoon total (June–September) rainfall. The OLR of two regions appears to be related to summer monsoon rainfall. One of the regions is located over the Head Bay of Bengal (near 22.5°N and 92.5°E) during May and the other one over the south Indian Ocean (near 30°S and 97.5°E) during April. The average OLR (index) for these two regions shows a strong and stable relationship with the Indian summer monsoon rainfall and they are found to be independent.

A multiple linear regression equation is developed to predict the Indian summer monsoon rainfall using these indexes and the empirical relations are verified on independent data.

Good results were obtained in forecasting the summer monsoon rainfall for the whole of India. The forecast of summer monsoon rainfall for west-central India and all-India rainfall for July also appears to be encouraging. The indexes, thus, seem to be useful in long-range forecasting of the Indian summer monsoon rainfall. Copyright © 2000 Royal Meteorological Society.

KEY WORDS: Indian Ocean; multiple regression analysis; Indian summer monsoon rainfall; outgoing longwave radiation

1. INTRODUCTION

The Indian summer monsoon (June–September) rainfall contributes about 75% of the total annual rainfall and exhibits considerable interannual variations. The agricultural economy of the country mainly depends on the monsoon rainfall. Hence the performance of the monsoon greatly affects the Indian economy. The long-range forecast of the monsoon rainfall is, therefore of significant importance in agricultural planning and other economic activities of the country.

Over the past 100 years attempts have been made using empirical techniques to long-range forecast the monsoon rainfall of the country (Walker, 1924; Banerjee, *et al.*, 1978; Shukla and Mooley, 1987; Hastenrath, 1988; Gowarikar *et al.*, 1989; Thapliyal, 1990; Krishnakumar *et al.*, 1992; Prasad and Singh, 1992). One of the difficulties encountered in such an attempt has been the change of relationship of the predictant and predictor with time. Hence, the empirical relationship developed cannot be taken for granted for its use over a longer period of time. Thus, the continuous monitoring of the relationship and at the same time exploring for a new parameter which demonstrates a better association with the Indian monsoon rainfall is necessary.

The parameters so far explored have been mainly of surface or oceanic–atmospheric origin obtained by conventional methods and no attempt has been made to analyse the satellite derived outgoing longwave radiation (OLR) for the study of such relationship. The OLR data bridge a wide gap in conventional meteorological data over the large remote land and vast oceanic areas. In the tropics OLR is largely modulated by cloud top temperature, and low OLR generally indicates convective systems, whereas high

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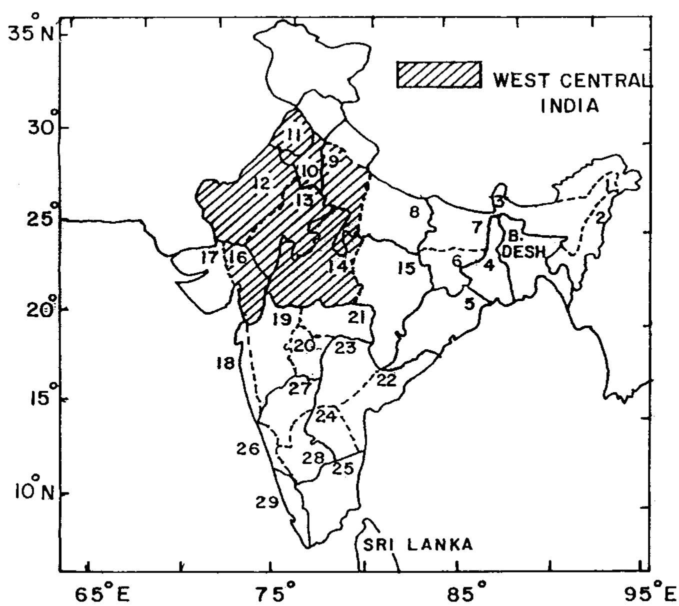
CCC 0899–8418/2000/010105–10$17.50

OLR is generally from cloud free regions indicating high surface temperature. The OLR data have been extensively used, apart from studying the earth radiation budget, in monitoring and understanding the tropical circulation changes and in modelling. Some examples are Murakami (1980), Prasad and Verma (1985), Horel *et al.* (1989), Chelliah and Arkin (1992), Kousky and Kayano (1994) and Moron (1995).

The present study examines the utility of OLR over the Indian Ocean in forecasting the Indian summer monsoon rainfall. The data and selection of predictors are discussed in Sections 2 and 3, respectively. Section 4 presents the prediction model. The discussion of results and important conclusions are made in Sections 5 and 6, respectively.

2. DATA

The monthly all-lndia rainfall and rainfall of 29 meteorological subdivisions (Figure 1) of India are taken from Parthasarathy *et al.* (1987) for the period 1974–1984. These have been updated through 1996 from the weekly weather reports. The all-India rainfall for each of the monsoon months (June, July, August and September) has been prepared by area weighting the 306 well-distributed rain gauges over country. The monthly rainfall series for west-central India has been prepared by the process of simple averaging of rainfall of the subdivisions lying in this region (Figure 1). The other data utilized are the monthly OLR over the domain 30°N–30°S and 40°E–100°E at 2.5° latitude and longitude grids for the period 1974–1996 excluding the calendar year 1978. These data were derived from the NOAA polar orbiting satellite and were obtained from Climate Analysis Center, NMC, Washington.



1. N. Assam
2. S. Assam
3. S. H. W. Bengal
4. G. W. Bengal
5. Orissa
6. Bihar Plateau
7. Bihar Plains
8. E. Uttar Pradesh
9. W. Uttar Pradesh
10. Haryana
11. Punjab
12. W. Rajasthan
13. E. Rajasthan
14. W. Madhya Pradesh
15. E. Madhya Pradesh
16. Gujarat
17. Saurashtra & Kutch
18. Konkan & Goa
19. M. Maharashtra
20. Marathwada
21. Vidarbha
22. C. Andhra Pradesh
23. Telangana
24. Royalseema
25. Tamil Nadu
26. C. Karnataka
27. N. Karnataka
28. S. Karnataka
29. Kerala

Figure 1. Meteorological subdivisions of India. West-central India is marked by hatching

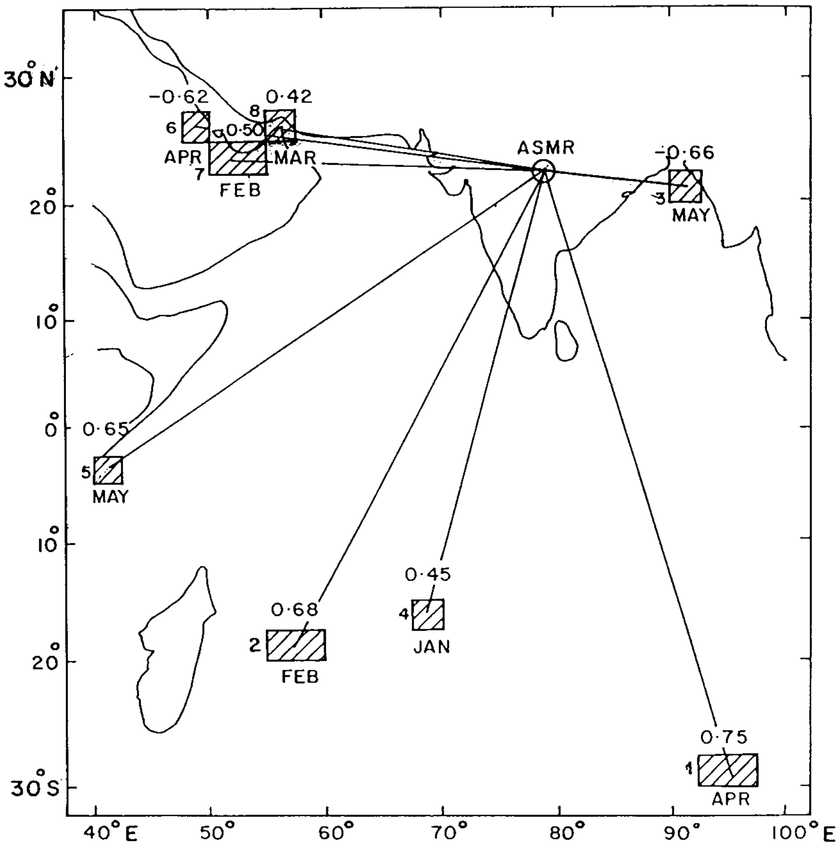


Figure 2. Map showing eight regions (hatched), indexes of OLR for which show significant lag correlation coefficient with the ASMR. The lag correlation coefficient is shown on the top of each region and the month of the lag is shown below

3. SELECTION OF PREDICTORS

The all-India summer monsoon i.e. June–September total rainfall (ASMR) has been correlated with OLR, at each of 2.5° latitude/longitude grid over the Indian Ocean (30°N–30°S and 40°E–100°E), for the preceding monsoon months (i.e. January–May). Based on the correlation maps for individual months the areas of high and significant correlation coefficient have been delineated. The OLR of all the grid points corresponding to each of these areas are averaged and indexes corresponding to these areas have been prepared. Eight regions were found where the indexes of OLR show significant correlation with the ASMR at the 5% level (Figure 2). The index for region 1 appears to be the best, showing the highest correlation coefficient with the ASMR followed by indexes for regions 2 and 3. These three indexes are found to have firm relationships (significant at 0.1% or higher level) with the ASMR. The first one is found to be located in April over the region 27.5°S–30°S and 92.5°E–97.5°E, the second one in February over the region 17.5°S–20°S and 55°E–60°E and the third one in May over the Head Bay of Bengal (20°N–22.5°N and 90°E–92.5°E). The intercorrelations of the first with the second and third are found to be 0.35 and − 0.29, respectively, whereas between the second and third it is found to be − 0.56. The index of regions 1 and 3 are not well correlated so they are a good possible pair of independent predictors. Hence we selected the indexes for regions 1 and 3 as two independent predictors of the ASMR and henceforth they are referred to simply as index 1 and index 2, respectively. The physical linkage of these two indexes with the ASMR is discussed in Section 5. The correlation coefficients of index 1 and index 2 with ASMR for an 11 year running window are presented in Figure 3. These indexes show a stable relationship with the ASMR with an increasing trend over the recent decade. A similar analysis of stability has also been performed with three other conventional predictors of the ASMR *viz*.: Northern hemispheric surface air temperature anomaly (average for January and February), Darwin surface pressure tendency (April minus January) and 500 hPa ridge axis position along 75°E over India during April. Their importance in forecasting ASMR has been discussed by various investigators (i.e. Shukla and Mooley, 1987; Hastenrath, 1988; Krishnakumar *et al*., 1992; Prasad and Singh, 1992). These three predictors are found to have a decreasing trend in the strength of the relationship with the ASMR, particularly over the recent decade when the relationship becomes insignificant. Also, in the case of the 500 hPa ridge axis position, a change of sign in the relationship is noticed (Figure 4). A similar result was also found by Hastenrath and Greichar (1993). The variation in the relationship between the predictant and predictor with time has been a major constraint in predicting the ASMR using empirical models developed earlier. In the present study, however, these selected OLR predictors *viz*.: index 1 and index 2 are found to be significant as well as stable during the recent decade. Hence they appear to be useful in the long-range prediction of ASMR.

4. PREDICTION MODEL

The multiple linear regression equation has been developed relating the Indian summer monsoon rainfall with indexes 1 and 2 as predictors. The relationship developed has the form:

$$R_i = a_0 + a_1 x_{i1} + a_2 x_{i2} + \varepsilon_i\,; \quad i = 1, 2, \ldots, n \text{ (where } n \text{ is the number of years)}$$

where R_i, is the predictant (i.e. Indian monsoon rainfall), a_0, is the constant term, a_1 and a_2 are the parameters of the model, x_{i1} and x_{i2} are the predictors (i.e. index 1 and index 2, respectively) considered and ϵ is the error associated with the predictant R_i.

To develop such empirical prediction models, long periods of past data for predictant and predictors are required. Because we have a limited period of 22 years (i.e. 1974–1996 with the exception of 1978) OLR data, we cannot have sufficient years of data, apart from development sample for independent testing of the model. Hence, it was decided to develop the model repeatedly using 21 years of data, leaving each time 1 year, randomly selected, for testing the model. In order to have sufficient independent test samples, the model was developed 15 times, each time leaving 1 year for testing the model. These

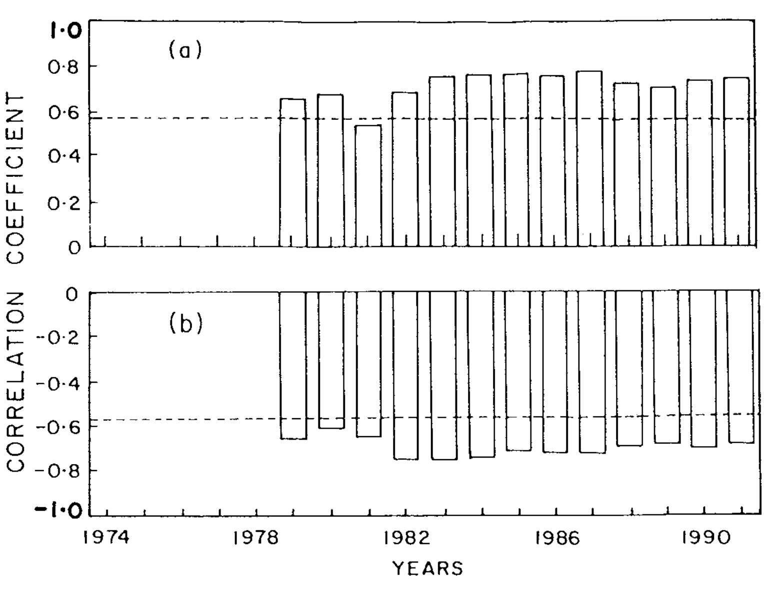


Figure 3. The correlation coefficient of the ASMR with (a) index 1 and (b) index 2 for an 11-year running window. Horizontal dashed line shows correlation coefficient significant at the 5% level

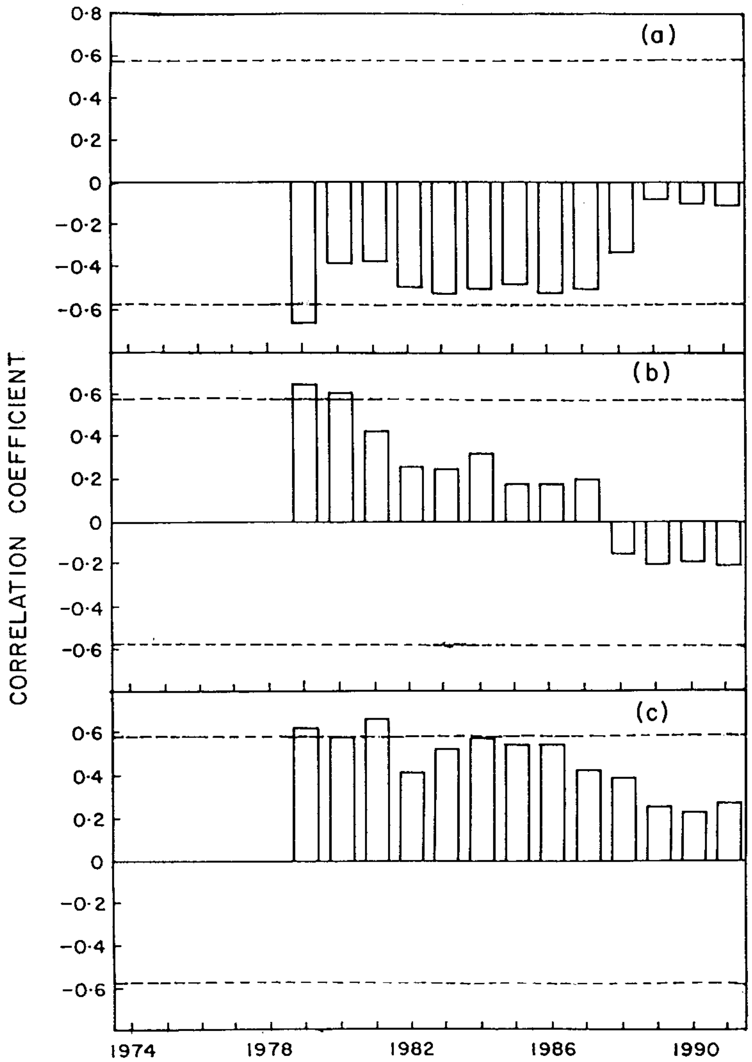


Figure 4. The same as for Figure 3 but for (a) Darwin surface tendency (April–January), (b) 500 hPa ridge axis position over India along 75°E in April and (c) Northern hemispheric surface air temperature averaged for January and February

randomly selected years were 1975–1977, 1979, 1981–1984, 1987–1989 and 1991–1994. Among these the following years have been drought years: 1979, 1982, 1984 and 1987, with the monsoon rainfall departure less than one standard deviation (S.D.), whereas the following years have been good years: 1975, 1983 and 1992, in which the monsoon rainfall exceeded one S.D.

The performance of the model has been determined, based on these 15 independent cases of forecast. The root mean square error (RMSE), absolute error (ABSE), Multiple correlation coefficient (MCC) and bias (BIAS) used by Nicholls (1984) have been computed as measures of the forecast performance.

5. RESULT AND DISCUSSION

In Section 3 we noted a strong and stable association of indexes 1 and 2 with the ASMR. The possible physical linkages of these two indexes could be given as follows. The index 1 area is a relatively cloud-free region of the southern Indian Ocean. Hence the variation in OLR in this case appears to represent the variation in the sea surface temperature (SST) of the region during April. As index 1 is found to be positively related with the ASMR, the high (low) value of the index accounts for high (low) ASMR. The SST has a comparatively longer memory and in this case, it appears that, through complex oceanic–atmospheric interactions, it influences the subsequent summer monsoon activity over the Indian subcontinent. In order to further substantiate the above relationship, the SSTs at the grid points over the southern Indian Ocean during April were analysed for the relationship with the ASMR. The SSTs in the vicinity of the region of index 1 were found to be positively associated (significant at 1% level) with the ASMR. This demonstrates that both the SST and the OLR of the region have significant positive association with the ASMR. However, in case of OLR the association was found to be stronger. Index 2 on other hand, is from the Head Bay of Bengal where thunderstorm activity prevails during the pre-monsoon month. As index 2 is found to have significant negative association with the ASMR, it appears that a low OLR associated with high thunderstorm activity over the Head Bay of Bengal during May (i.e. pre-monsoon month) enhances the summer monsoon activity through the release of latent heat.

These indexes have been further analysed for the study of spatial and temporal variation of the relationship with the monsoon rainfall. The correlation coefficients of the indexes 1 and 2 with the all-India rainfall for each of the monsoon months are presented in Table I. The relationship is found to be at a minimum during June and August and at a maximum during July and September. The association however, is strongest in July. As June is the northward advancing period of the monsoon, the weak association of rainfall of the month with these indexes is understood a little. However, the weak association of these indexes with rainfall for the month of August is not clear.

In order to examine whether this procedure could be useful in predicting the regional scale summer monsoon rainfall, we correlated each of the indexes with summer monsoon rainfall for each of the contiguous meteorological subdivisions of India. The spatial correlation pattern with each of the indexes are presented in Figure 5. Index 1 appears to have a significant positive relationship with the rainfall of meteorological subdivisions lying mainly in peninsular India, whereas index 2 appears to have a significant negative relationship with the monsoon rainfall of the meteorological subdivisions lying in central and west-India. Thus, it appears that these two indexes combined could be useful in forecasting the ASMR. Each of these two indexes also show a high correlation with the summer monsoon rainfall of west-central India (Table I). Hence they also appear to be useful in forecasting the summer monsoon rainfall of the region.

As indexes 1 and 2 are strongly related with the ASMR and they also demonstrate a better relationship in the case of summer monsoon rainfall for west-central India and all-India rainfall for July, the prediction models were developed as discussed in Section 4 to forecast rainfall in all three cases (i.e. ASMR, west-central India monsoon rainfall and all-India rainfall for July). The performance of the model is verified on 15 independent years of data for ASMR and 14 years for other cases. The mean and S.D. of rainfall for these three cases considered (based on data from 1974 to 1996) are given in the last column of Table II. As rainfall in the above three cases is found to have different variability, the test statistics of forecast computed for these cases cannot be compared.

Table I. Correlation Coefficient (CC) of all-India (monthly and seasonal) and west-central India (seasonal) rainfall with index 1 and index 2 ($CC = 0.42$, significant at 5% level)

Index	All-India rainfall for					West-central India rainfall for June–September
	June	July	August	September	June–September	
1	0.35	0.64	0.22	0.57	0.75	0.55
2	−0.29	−0.64	−0.23	−0.50	−0.66	−0.65

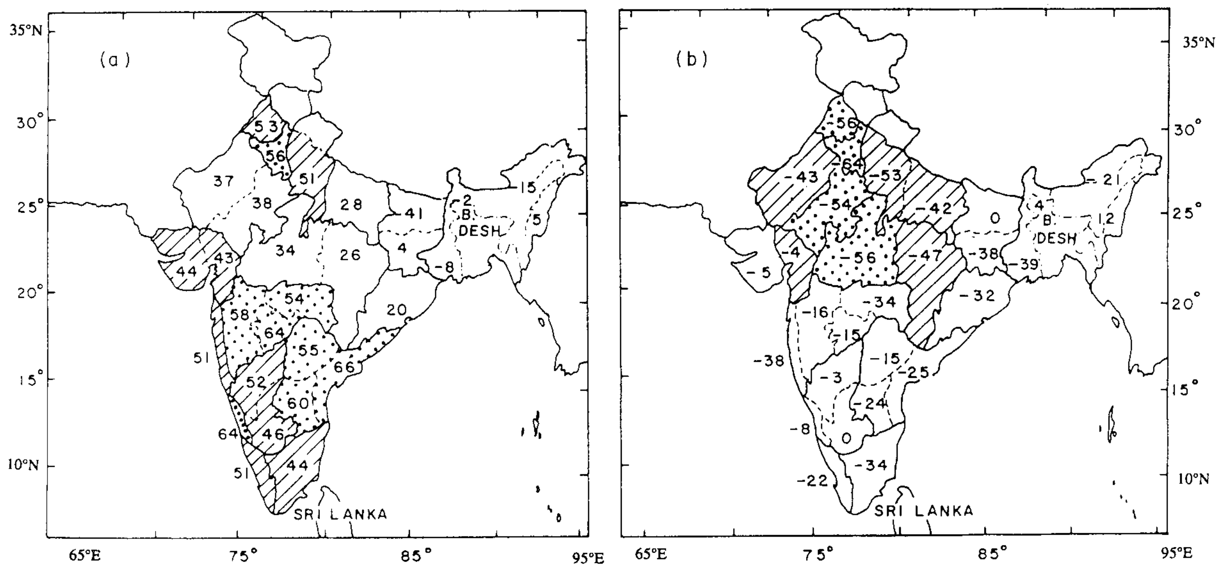


Figure 5. Correlation coefficient of the summer monsoon rainfall for each of the 29 meteorological subdivisions with (a) index 1 and (b) index 2. Hatching (striping) shows correlation coefficient significant at 5% (1%) level

The observed and forecasted rainfall for independent years selected are presented in Figure 6. The forecast for ASMR appears to be in close agreement with the observed rainfall (Figure 6(a)). This is also evidenced from the high magnitude of MCC (0.91) found in this case. This means that 83% of the variance of rainfall is accounted for through the forecast model. Also, all the observed and forecasted rainfall in this case is found to be in phase with the only exception being the years 1976 and 1991. The monsoon rainfall in these 2 years appears to be close to normal and the forecasted rainfall is found within $\pm 6\%$ of the observed rainfall. Also, all the major flood years and all the major drought years except 1982 with rainfall departure in excess or less than 1 S.D. are well predicted. The forecast model thus appears to perform quite well. The RMSE, BIAS and ABSE (Table II) are also noticed to be low (which are 3.8, 0.1, and 3.2 cm, respectively).

A good resemblance is also noticed in observed and forecasted rainfall for the summer monsoon rainfall of west-central India (Figure 6(b)) and all-India rainfall for July (Figure 6(c)). The MCCs in these cases are found to be 0.80 and 0.76, respectively and the forecast appears to be negatively biased (BIAS = -2.0 cm and -0.2 cm, respectively). The RMSE and ABSE are noted to be less than their respective S.D.s. In the case of summer monsoon rainfall for west-central India, dry years appear to be better forecasted as compared with flood years. Also, dry July appears to be better forecasted as compared with wet July in the case of all-India rainfall for July.

Table II. Measures of forecast performance together with mean and standard deviation (S.D.)

No.	Region of forecast	Forecast period	RMSE (cm)	BIAS (cm)	ABSE (cm)	MCC	Mean	S.D. (cm)
1	All-India	June to September	3.1	0.1	3.2	0.91	84.8	8.2
2	All-India	July	2.4	−0.2	2.0	0.76	26.8	3.1
3	West-central India	June to September	10.1	−2.0	7.9	0.80	62.8	14.5

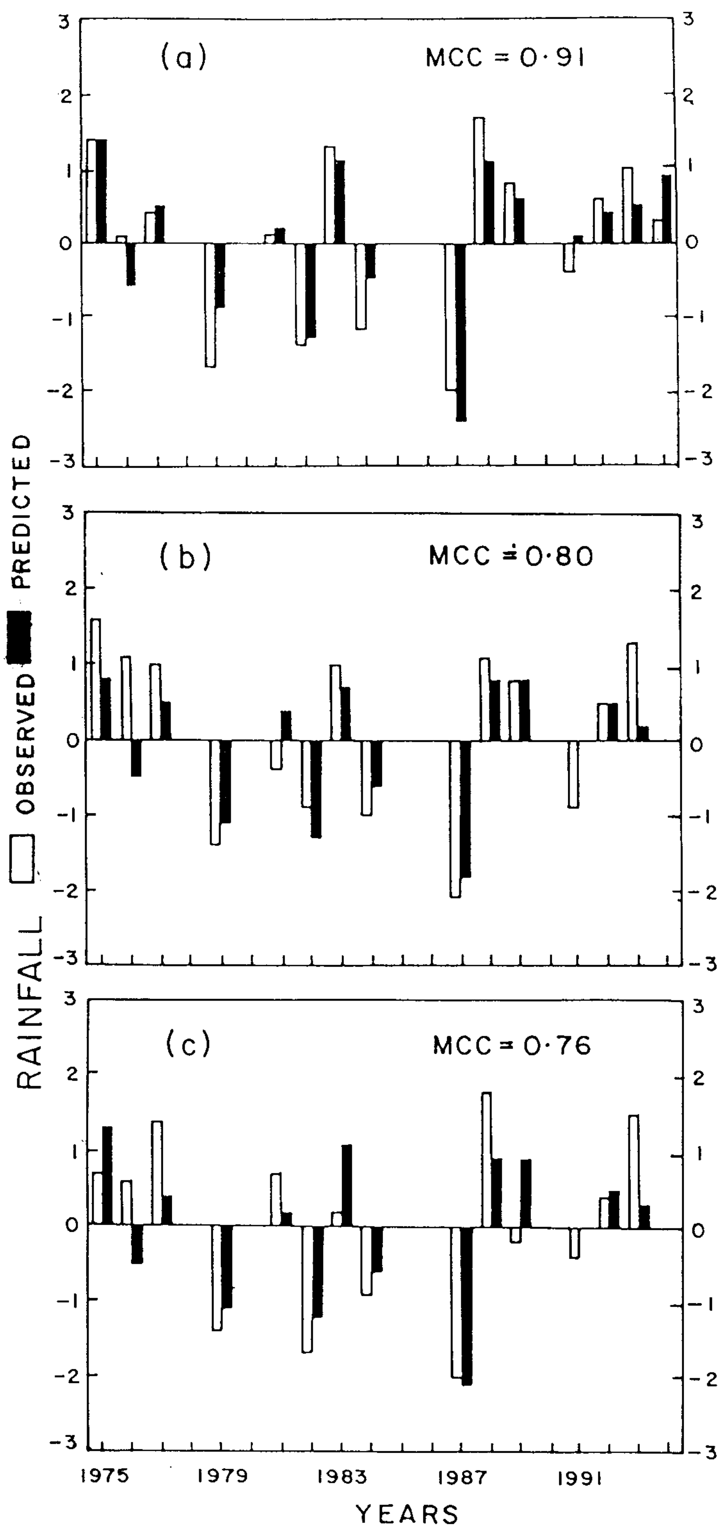


Figure 6. Observed and forecasted (normalized) rainfall for (a) all-India (June–September); (b) west-central (June–September); and (c) all-India (July)

6. CONCLUSIONS

A detailed study of the relationship between the Indian summer monsoon rainfall and OLR over the Indian Ocean has been made. Based on this study the following conclusion are drawn.

1. The OLR over the south Indian Ocean during April (i.e. index 1) has a strong positive association with the ASMR. This indicates that a high OLR over the region during April (representing high SST) enhances the subsequent summer monsoon activity through complex ocean–atmospheric interaction. Also, OLR in pre-monsoon month of May over the Head Bay of Bengal (index 2) appears to have a significant negative association with the ASMR. In this case it appears that the pre-monsoon (i.e. May) thunderstorm activity over the region enhances the summer monsoon activity through the release of latent heat.
2. These two indexes are found to be independent to each other and their relationship with the ASMR also appears to be stable.
3. Furthermore, it is found that index 1 has a significant positive association with the summer monsoon rainfall of meteorological subdivisions lying in peninsular India, whereas index 2 has a significant negative relationship with the summer monsoon rainfall of meteorological subdivisions lying in central and west-India.
4. Index 1 and index 2 seem to be better related to the all-India rainfall of July as compared to other months of the season.
5. The forecast of the ASMR through the multiple regression model using indexes 1 and 2 as predictors appears to perform quite satisfactory. Also, the performance of forecasts for the monsoon rainfall of west-central India and all-India rainfall for July, using these indexes is found to be encouraging.

The study, thus brings out the importance of satellite derived OLR of the above two regions in long-range forecast for Indian summer monsoon rainfall.

ACKNOWLEDGEMENTS

The authors wish to thank Dr G.B. Pant, Director, and Dr S.S. Singh, Head, Forecasting Research Division, Indian Institute of Tropical Meteorology, Pune for providing facilities and encouragement. We are also thankful to the unknown referees and Dr G.R. McGregor for their valuable suggestions and comments which helped improve the text of the paper.

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